Performance of Advanced Hybrid Link Adaptation Algorithms in Mobile Radio Channel

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Abstract. *The fast power adaptation is essential for WCDMA based mobile radio networks, as 3G UMTS. Although the first version of UMTS has been released in 1999 (Release 99) evolution was not finished yet. Quality of Service (QoS) and user data rate (e.g. HSDPA and HSUPA) are continuously increasing from release to release. Even though link adaptation frequency (1500 times per second) seems to be enough to span accidental fadings of mobile radio channel, used link adaptation algorithm is based on non-actual information about mobile radio channel state, which causes transmitter reaction delay to the actual channel state. Usage of appropriate prediction method to estimate near future channel state seems to be a valuable step to improve hybrid link adaptation algorithm. In this article we have described and simulated the new SIR-slot based advanced link adaptation algorithms. Algorithms were designed to increase efficiency of data transmission among a user equipment and base stations (uplink) for different simulation environments (pedestrian channel with mobile subscriber speed 5 km/h, 15 km/h and vehicular channel with speed 45 km/h).*

Keywords

Next generation mobile networks, link adaptation algorithm, prediction methods, uplink data transmission efficiency, hybrid adaptation.

1. Introduction

The one of the latest 3G UMTS Release 05 (already active in the field) has brought advanced downlink data transmission HSDPA (High-Speed Downlink Packet Access) service, where the highest theoretical L1 data speed is above 10 Mbps. HSDPA implementation includes (H-ARQ) Hybrid Automatic Repeat Request, AMC (Adaptive Modulation and Coding), fast cell search, and advanced receiver design and the prepared UMTS Release 06 includes MIMO (Multiple-Input Multiple-Output) communication [3]. In the reverse (uplink) direction the HSUPA (High Speed Uplink Packet Access) is available from Release 06. HSUPA implementation includes higher-order modulation, shorter TTI (Transmission Time Interval), H-ARQ, etc. Theoretical L1 uplink data rate is above 5.75 Mbps [4]. The new specified services prove that the evolution of 3G is still in progress, straightforward to LTE (Long Term Evolution) and there is an aim to achieve data rates and network throughput which will be interesting in comparison to fixed data networks. Even if, HSDPA/HSUPA implementation includes a lot of new modern techniques, these are working with certain traffic delay. We see the solution of this problem in using of appropriate mobile radio channel state prediction method [1], [5].

2. Mobile Radio Channel Prediction Model

The prediction of mobile radio channel is based on observed impulse responses, where one of the limiting factors is the estimation error. We assume that the channel can be approximated as time invariant over a block of symbols, because the broadband symbol rate is much higher in comparison with the channel fading rate (time variation of the channel during the estimation interval increases the estimation error) [1].

The principle of basic prediction model is depicted in Fig. 1 where relations between a transmitter and a receiver can be seen. The outer loop power control (OuLPC), located in the receiver, adapts (based on BER) the required SIR_R $\gamma_i^t(t)$ to keep the required QoS^t. The receiver calculates the error $e_{\gamma i}(t)$, what is the difference between the required SIR_R $\gamma_i^t(t)$ and the actually achieved (measured) SIR_A $\hat{\gamma}_i(t)$. A measurement of SIR_A $\hat{\gamma}_i(t)$ is done in block F_i, where a suitable filter is located. The input signal to block F_i includes a fragment of the valid signal, an interference from other transmitters and a noise $e_i^{AWGN}(t)$.

The mobile radio channel gain $G_i(t)$ [dB], the interferece $I_i(t)$ [dB], and the fragment of transmission power $\delta^p{}_i(t)$ [dB] are represented by the block named environment. The second output of F_i is information about the actual received signal power level $p_i(t)$, which is also the input of a prediction block P_i. Predictor P_i includes its own internal memory $\vec{M}$ to store actual and previous power level samples of the received signal [$p_i(t-1)$, …, $p_i(t-m)$], where m is the memory size. P_i output is a predicted sample (estimation of future mobile radio channel state) $\hat{p}_i(t+L)$, where L is the prediction interval. The presented model uses a fixed power step Δp to control transmitter output power level, therefore P_i output is the difference $\bar{d}_i(t)$ between the required power level $p^t_i(t)$ and the estimated $\hat{p}_i(t+L)$ one. The error $e_{\gamma i}(t)$ and the difference $\bar{d}_i(t)$ are transformed according to predefined rules to the TPC (Transmitter Power Control) command $s_i(t)$ in the block R_i. The transmitted TPC command can be affected by error $e_i^s(t)$ in the backward control channel. The TPC command is decoded in block D_i (the closed loop power control (CLPC)). It is obvious that loop power control accuracy depends on traffic delay (n_p samples) of TPC command delivery and $\hat{\gamma}_i(t)$ measurement delay (n_m samples). The block R_i always causes one sample delay (time to process the TPC command), therefore the total delay of one power control cycle n_{total}:

$$n_{total} = 1 + n_p + n_m . \quad (1)$$

The main goal of a predictor is to eliminate the total delay n_{total}, what can by done by estimation of mobile radio channel n_{total} samples in advance [1], [5].

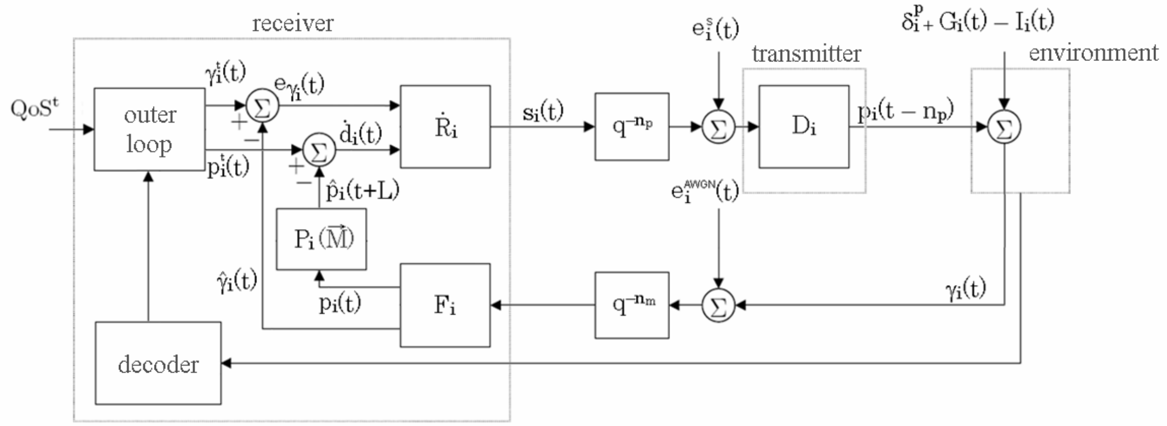

Fig. 1. Principle of basic prediction model.

3. Advanced Hybrid Link Adaptation Algorithm

The designed hybrid link adaptation algorithm (Fig. 2.a) is based on the standard link adaptation algorithm used in UMTS/FDD system [6]. The hybrid link algorithm also includes an adaptive modulation schema, a coding schema control and a decision about power step is based on the actual SIR [7]. The required fixed power step is sent in every time slot. OpLPC sets up initial power for UE P_{UE_out} [dBm]:

$$P_{UE\_out} \geq P_{BS\_out} - \left(L_{PATH-LOSS} + L_{RAYLEIGH} + L_{SHADOW}\right) \quad (2)$$

where P_{BS_out} [dBm] is the output power of uplink control channel (UCCH) (measurement is done on control channel, because its format and parameters are not changed during connection), $L_{PATH-LOSS}$ [dB] is the path loss of the selected environment, $L_{RAYLEIGH}$ [dB] is the Rayleigh fading loss [7] and L_{SHADOW} [dB] is the log-normal shadow fading loss. CLPC is used for UE transmission power adjustment after the time slot transmission. The decision is based on a comparison of SIR_A and the required SIR_R. If SIR_A is greater or equal to SIR_R, then the transmitter power is decreased (power control step ΔP [dB]). On the contrary, if SIR_R is greater than SIR_A, the power is increased:

```
if (SIR_A > SIR_R) then
    if (SIR_A > SIR_R + ΔSIR) then P_MS_out - ΔP
    end;
else if (SIR_A ≤ SIR_R) then  P_MS_out + ΔP
end;
```

where ΔSIR [dB] is the safety interval, ΔP [dB] is the power control step. The advantage of the proposed hybrid link algorithm lies in a possibility to control the modulation and coding schema of the uplink data channel (UDCH). In case of a bad mobile radio channel condition, the coding schema is updated as the first one and the modulation schema as the second one. The simplified algorithm code is:

```
if     (SIR_A ≤ SIR_R_act - ΔSIR)
            if    (P_MS_out == P_MS_max)
                 if    (COD_A is not the strongest available) then set stronger coding
                                                  scheme as COD_A
                 elseif (COD_A is the strongest available) then set lower-order modulation
                                                  scheme as MOD_A
            end;
elseif (SIR_A ≥ SIR_R_act - ΔSIR)
            if    (COD_A is the weakest available) then set higher-order modulation scheme
                                                  as MOD_A
            elseif (COD_A is not the weakest available) set weaker coding schema as COD_A
elseif (SIR_A > SIR_R_act - ΔSIR) and (SIR_A < SIR_R_act+ ΔSIR) then do not change MOD_A and
                                                  COD_A
end;
```

Information about the momentary used transmission schema in UDCH is sent through the control channel [8].

The Outer loop power control (OuLPC) adjusts the required SIR_R to keep the required QoS.

The advanced hybrid link adaptation schema includes prediction methods, where near future channel state is estimated and this forecast is used to control power level (power step value). The advanced hybrid link adaptation algorithm flow diagram is depicted in Fig. 2 [13].

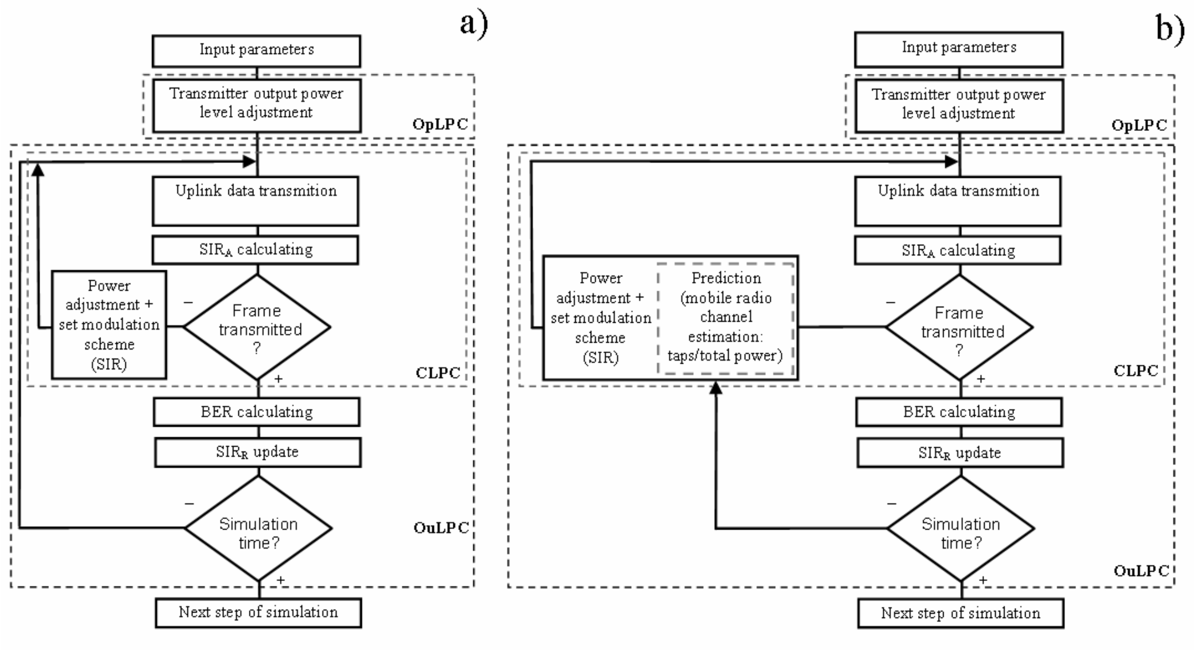

Fig. 2. a) Hybrid link adaptation algorithm [7], [9]. b) Advanced hybrid link adaptation algorithm.

4. Prediction Methods

There are several suitable mobile radio channel state predictors, deeply described in [1]. The simplest one is the sub-sampled direct linear FIR (Finite Impulse Response) predictor of the total mobile radio channel power, which performance is not sufficient to be used at higher UE equipment velocity (e.g. acceleration of UE increases the number of deep fadings of mobile radio channel [1]):

$$\hat{h}(t+L \mid t) = \varphi(t)\theta \tag{3}$$

where $\hat{h}$ is the estimated value, L denotes the prediction interval, the column vector $\boldsymbol{\theta} = [\theta_1 \dots \theta_N]^T$ represents the complex valued predictor coefficients, and $\boldsymbol{\varphi}(t)$ is the row vector of past channel samples:

$$\varphi(t) = [h(t), h(t-\Delta t), \dots h(t-(N-1)\Delta t)] \tag{4}$$

where $h(t)$ denotes the complex valued observation, Δt denotes the time spacing between samples, and N is the number of predictor coefficients. The prediction error is given by:

$$\varepsilon_c(t) = h(t) - \hat{h}(t \mid t-L). \tag{5}$$

Prediction error has zero mean and therefore the minimum mean square error MMSE criteria to find predictor coefficients, will be equal to the variance:

$$\sigma_{\varepsilon c}^2 = E\left\{|\varepsilon_c(t)|^2\right\}. \tag{6}$$

Predictor's performance is expressed by a predictor gain $G(L)$:

$$G(L) = 10\log_{10} \frac{E\left[(h - E[h])^2\right]}{E[\varepsilon_c]}. \tag{7}$$

The efficient total power prediction used in simulations can be seen as the sum of the squared magnitude of the M taps predictions [1], [2]:

$$\hat{p}(t+L) = \sum_{k=1}^{N} \left|\hat{h}_k(t+L)\right|^2. \tag{8}$$

The prediction interval L depends on the time spacing Δt between the observed channel samples $y(t)$, therefore if there is a request to increase a prediction interval, input samples have to be subsampled.

The effect of observed samples subsampling against prediction gain $G(L)$ is not high in the case of a low transceiver velocity. With the increasing transceiver velocity the number of deep fadings is rising and the designed subsampled predictor gain $G(L)$ is getting low. The subsampling of input samples causes loss of details at higher velocity, what can be eliminated by using an iterative FIR predictor.

The adaptive iterative predictor reduces complexity because only one predictor has to be adapted for any prediction range. The proposed iterative predictor is less sensitive to errors with assumptions made in the filter model [1]. The principle of iterative predictor lies in reuse of already predicted samples to predict another one (up to the interval of prediction). The general model of L-step predictor can be described [1]:

$$\hat{h}(t+L\,|\,t)=\varphi(t)\hat{\theta}(t+L\,|\,t). \tag{9}$$

The required prediction range is obtained in m-iterations, where m is divider of L, therefore subsampled predictor memory φ is extended into the future using predicted values:

$$\varphi(t+km\,|\,t)=[\hat{h}(t+km\,|\,t),...h(t+m\,|\,t),h(t),... \hat{h}(t+T-km)] \tag{10}$$

where $k\in\langle 1,2,\ldots,T\rangle$ and T denotes the size of regressor. FIR predictor used for prediction of time varying system has time varying coefficients, therefore the output of the iterated one-step predictor is:

$$\hat{h}(t+m\,|\,t)=\varphi(t)\ \hat{\theta}_m(t+m\,|\,t),$$

$$\hat{h}(t+2m\,|\,t)=\varphi(t+m\,|\,t)\ \hat{\theta}_m(t+2m\,|\,t),$$

$$\vdots$$

$$\hat{h}(t+L\,|\,t)=\varphi(t+L-m\,|\,t)\ \hat{\theta}_m(t+L\,|\,t). \tag{11}$$

where $\hat{\theta}_m(t+km|t)$ denotes an m-step predictor with coefficients extrapolated km steps ahead [1].

5. Simulation Model Assumptions

Mathematical model used in simulation includes WCDMA based base station (receiver only), mobile station (transmitter only), mobile radio channel model and hybrid link adaptation block (Transmitter Power Coding and Modulation Control - TPCMC command related blocks). The block diagram of simulation model is depicted on the fig. 3. Presented model does not include downlink control and data transport channels, but continuous random data stream is generated in *information source* block. There is only one uplink *errorless control channel* created to transport feedback TPCMC command. Downlink data stream is secured in *channel coder,* after that *spread* (data stream is converted to chip rate 3.84 Mchip/s over the selected spreading factor) and *scrambled* (PN code). The last block - transmitter block in the row is *digital modulator* and output *amplifier* [10, 12]. Output samples are complex sample $\dot{x}_i(t)=i_i(t)+jq_i(t)$ at chip rate, where absolute value of complex sample represents nominal digital output power level $p_i^r(t)=|\dot{x}_i(t)|$.

Inner cell interference $I_i(t)$ is represented by AWGN at the required level. Rayleigh mobile radio channel model $G_i(t)$ is based on the Clark's statistical model of mobile radio channel [6]. The environment block includes fragmentation of the transmitting signal δ^p_i.

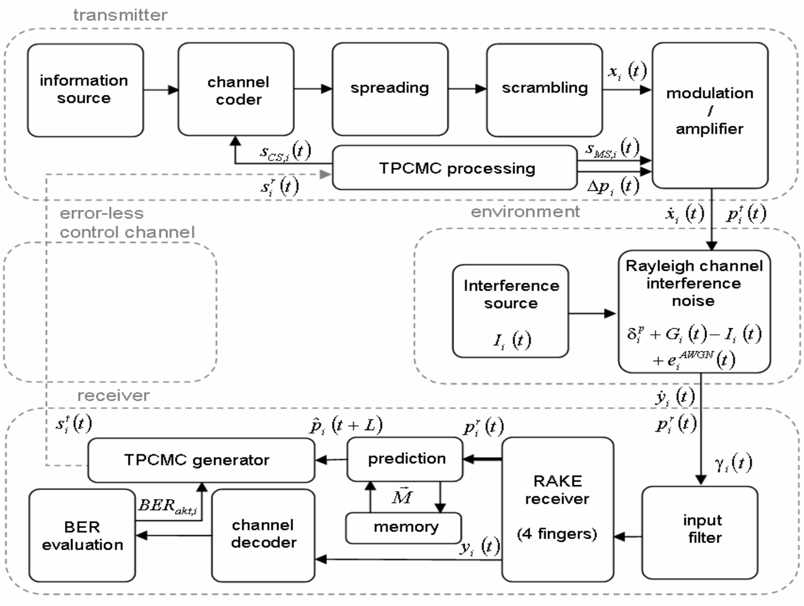

Fig. 3. WCDMA based transmitter / receiver block diagram.

The received signal $\dot{y}_i(t)$ is filtered and resampled in the *input filter* block. The main received signal processing is done in the *RAKE receiver*, where four main taps are traced. The RAKE receiver finger includes a demodulator, a delay block, a descrambling block, and a despreading block. Tracked paths are weighted and combined to one data stream $y_i(t)$, which is decoded in the *channel decoder*. The block *BER evaluation* compares the received data stream with the sent delayed data stream (logical connection is not depicted, this process is running in the background of simulation). The *prediction* block inputs represent information about the total received power level $p^r_i(t)$ (or taps received power level). An estimation of a future channel state $\hat{p}_i(t+L)$ and actual BER ($BER_{\mathrm{akt},i}$) is used to create an appropriate TPCMC command. The transmitted TPCMC command includes the transmitter power step value $\Delta p_i(t)$, the required coding schema $s_{CS,i}(t)$, and the required modulation schema $s_{MS,i}(t)$.

The presented simulation model simplifications have no influence to the achieved prediction gain. One of the model advantages is the possibility of simulation repetition with the same mobile radio channel behavior (including initial state and changes). Therefore prediction methods can be compared under the same simulation conditions.

6. Results

The simulation has been run for 100 frames (stabilization of power loop control parameters takes 20 frames). UE transmitted test data pattern (random data source). Simulation results were achieved with spreading factor 8 and convolution coder 1/2. The mobile radio channel model was set to pedestrian (velocity range: 5 m/h and 15 m/h) or vehicular (velocity range: 45 m/h) [11]. The interference level average value was set to -48 dBm, what represents maximum output power level boundary condition for UE (UE maximum output power level = 33 dBm and minimum output power level = 15 dBm). Both algorithms were compared (Fig. 2) where the advanced hybrid link adaptation algorithm with non-adaptive power prediction (TPCMC n_{total}=1) and the advanced hybrid link adaptation algorithm with adaptive iterative prediction (TPCMC n_{total}>1) were added into the simulation model. The non-adaptive total power prediction interval L was set to 1 (1 time slot) because TPCMC command processing and traffic delay was set to 1 time slot at the presented model. The prediction interval L at iterative prediction was set from 2 to 10. The L is equal to the number of iterations to estimate the mobile radio channel state at the required time slot. There was the fixed number of predictor coefficients N=6 used for both predictors. The achieved average L1 data BERs at various UE velocity are depicted in graph in Fig. 4. The link adaptation algorithm efficiency can be expressed through the average difference between SIR_R and SIR_A: $e_{SIR} = E[SIR_R - SIR_A]$ where simulation shows that acceptable are values of $|e_{SIR}| < 3$ dB.

During simulations the following values were achieved: minimum $|e_{SIR}| > 0.1$ dB (TPCMC n_{total}=0) and maximum $|e_{SIR}| < 1.72$ dB (TPCMC n_{total}=10), what confirms that the link adaptation algorithms parameters were set properly. Very important indicator of prediction performance is the achieved prediction gain. The advanced hybrid link adaptation algorithm with power prediction achieved the maximum prediction gain G(1 time slot) of 3.61 dB (5 km/h pedestrian), but the increase of TPCMC traffic delay (length of prediction) causes the decreasing of the prediction gain. The simulation of the advanced hybrid link adaption algorithm in vehicular environment under UE velocity 45 km/h shows that the used prediction performance is insufficient to achieve lower L1 BER. The achieved gain values were bellow 0.5 dB.

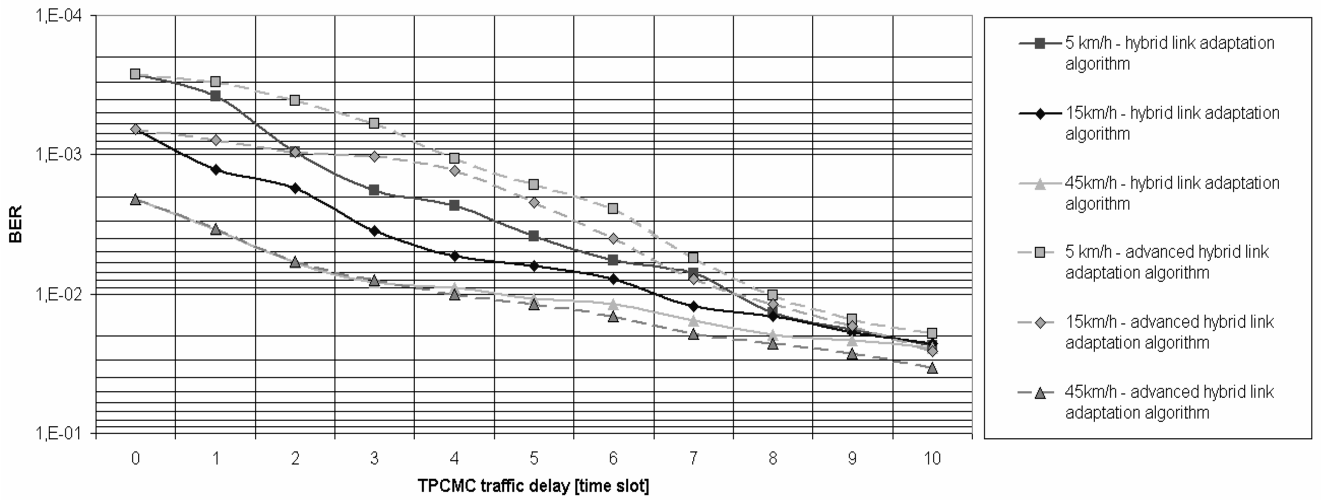

Fig. 4. Average L1 data BERs at various MS velocity and TPCMC traffic delay.

7. Conclusion

The simulation results depicted in Fig. 4 show that the application of appropriate mobile radio channel prediction methods is meaningful. The maximum improvement was observed in the pedestrian environment (5 km/h) when TPCMC was delayed about three time slots (n_{total}=3): The hybrid link algorithm achieved the average bit error rate BER = 1.813E-03 in comparison with the average BER = 0.602E-03 of the advanced hybrid link algorithm. The simulation also shows that the presented advanced hybrid link algorithm is not powerful enough to increase high data rate (e.g. decrease BER, because all wrong transmitted data block have to be retransmitted) at higher UE velocity (vehicular velocity range and environment) in comparison with the required computation and memory requirements. Average L1 data BER was not decreased, even at higher TPCMC n_{total} BER was increased. Even if the performance of the used power prediction is not sufficient to keep high data rate at high UE velocity, there is still a space to improve prediction methods to achieve valuable results, e.g. adaptive iterative prediction can be used to estimate several samples, where the short-term prediction interval can be used to generate TPCMC command and long-term to estimate the trend of mobile radio channel.

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